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Examining the Street Patterns in Izmir in the 19th Century: A network based spatial analysis

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Abstract

Izmir, or the Greek Smyrna, had been the largest seaport on the Aegean coast of Anatolia, since the ancient times. It has experienced a notable growth, after the devastating earthquake in 1686 and has become one of the most important ports of the Eastern Mediterranean starting from the eighteenth century. There is an extensive literature on the past social and economic life of the City of Izmir, Turkey. However, the historic spatial analysis of the city is largely neglected, similar to the most studies on Asian cities. The graph theory is used to compare the spatial structure of street networks in the quarters (neighborhoods) of Izmir in the 19th century. Six different indices are used: (1) edge density, (2) edge sinuosity, (3) eta index, (4) node density, (5) order of a node, and (6) beta index. The results showed that the urban street pattern varies with the cultural landscape. The findings regarding that that the Armenian, Frank and Greek quarters do not differ significantly in the means for the three local indices, and the Turkish quarter and the Jewish quarter differ from these three quarters and from each other, point out that religion may have determining role in forming the spatial structure. Further research may consider different spatial indices and may focus on a wider time spectrum to generalize these results.

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*Keywords:*Network analysis; street pattern; İzmir; spatial indices

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1. Introduction

Networks, including transportation and communication, define the level and the way of human interactions, and play a significant role in the localization process of urban areas (Borusso, 2003). As correctly stated by Lynch (1981), the modification of the urban structure is a human act. Pillsbury (1970) argues that the urban street pattern is a potential indicator of culture. The geographers have used different parameters including religion, word usage and pronunciation and place names in defining cultural regions. However, the street patterns were not fully utilized (Pillsbury, 1970). This study aims to test the hypothesis that the urban street pattern is an indicator of the cultural landscape using the graph theory. The graph theory is a branch of mathematics, which deals with the study of graphs. A graph is basically composed of nodes (or vertices) and edges (or links) (Fig 1). The edges may have directional information. In recent years, the graph theory has been successfully adapted to various fields (Bin and Zhongyi, 2010).

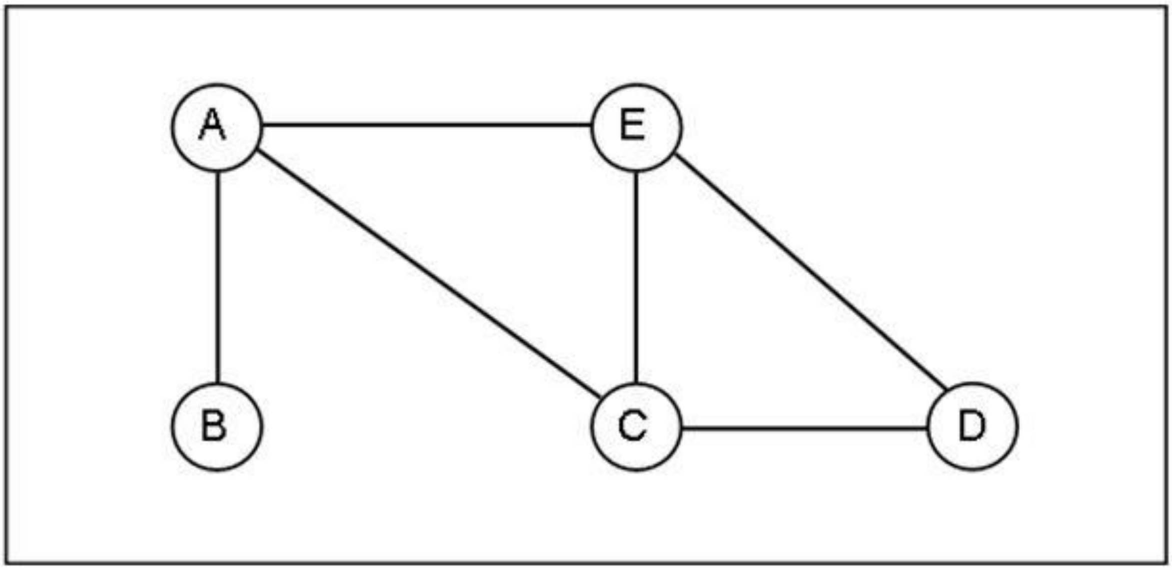

Fig.1. A graph with five nodes and six (non-directional) edges.

A considerable number of indices have been developed making use of the graph theory to define the characteristics of networks. Some of these indices are used in the studies that examine and compare urban street patterns. For example, Borusso (2003) derives route density indices for the Trieste Municipality area in Italy using grid density estimation and kernel density estimation. Crucitti et al. (2006) measure centrality indices in 18 world cities. A one-square-mile sample is selected for each city and four node centrality indices, including closeness centrality, betweenness, straightness, and information, are evaluated to examine the urban street patterns. Buhl et al. (2006) examine a sample of street patterns from 41 non-planned settlements in Africa, Central America, Europe, and India ranging from 45 to 339 nodes. Indices for topological patterns, network efficiency, and network robustness are considered. The studies on street network analysis based on the graph theory are mostly limited to the derivation of spatial indices and evaluating them quantitatively. However, the street pattern is a spatial outcome of human interactions (Borruso, 2003) and it is a potential indicator of culture (Pillsbury, 1970). In this study, the graph theory is used to compare the spatial structure of street networks in the quarters (neighborhoods) of Izmir in the 19th century.

2. The city of Izmir

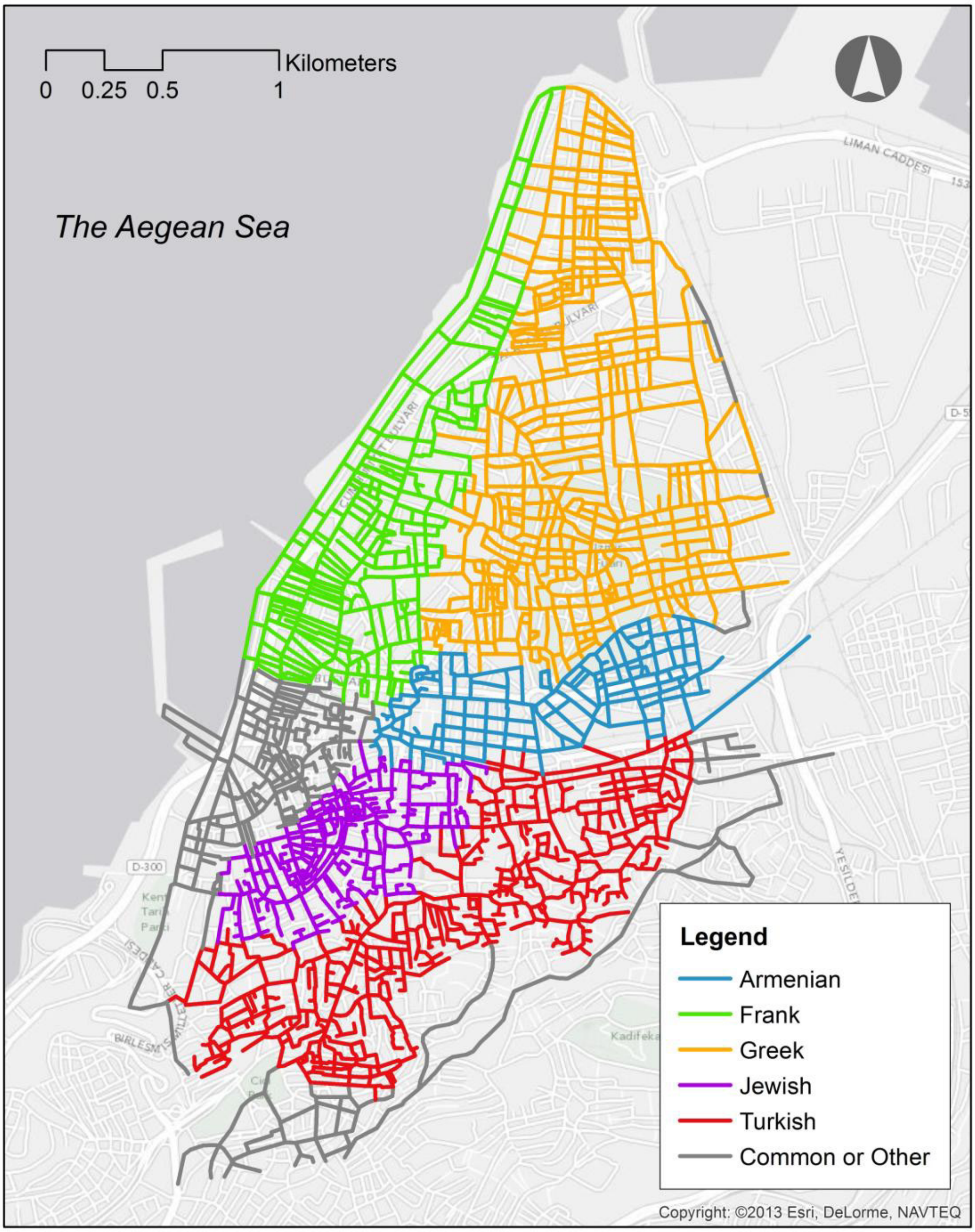

Fig. 2. The street data adopted from the "City Plan of Smyrna" published in Leipzig, by Joseph Meyer (1796-1856) and reprinted in Smyrnelis (2013) (The base map is created using the ArcGIS® software by Esri. ArcGIS® and ArcMap™ are the intellectual property of Esri and are used herein under license. Copyright © Esri.ESRI, DeLorme, NAVTEQ, 2013).

The city of Izmir is selected for its long-lasted cultural and ethnic diversity and its rich historical background. Izmir, or the Greek “Smyrna”, was one of the three great cities of Asia Minor during Roman Times with Ephesus and Pergamum. It became the capital of a Byzantine providence after the split of Roman Empire into Eastern Roman (Greek Byzantine) Empire and Western Roman (Latin Roman) Empire at the end of the fourth century. Smyrna was taken by Ottoman Turks in 1425 (Freely, 2004). The city experienced a notable growth after the devastating earthquake in 1686 and become the chief port of the eastern Mediterranean during the eighteenth century (Wagstaff, 1985). Izmir had then been one of the largest seaports on the Aegean coast of Anatolia during the ancient times (Freely, 2004). The social, cultural, and spatial structure of Izmir in the nineteenth century was quite different from the one in the twentieth century. In the twentieth century, Izmir has become a city that resembles the characteristics of the modern Turkish Republic (Goffman, 1999). However in the 19th century, Izmir was a part of an imperial order. Its population was significantly heterogeneous, characterized by a multi-lingual and mixed-religion structure (Kırlı, 2007). There is an extensive literature on the past social and economic life of the City of Izmir, Turkey. However, the historical spatial analysis of the city has been largely neglected, similar to the most studies on Asian cities. By the end of the 18th century, the city of Izmir was spatially composed of distinguishable quarters: including (1) the Armenian quarter, the Frank (French) quarter, (3) the Greek quarter, (4) the Jewish Quarter, and (5) the Turkish quarter. A small Arab quarter was also present. These quarters were reserved for the members of the same community. These quarters were reported to differ in daily social life and economic activities, as well as access to public services and utilities (Smyrnelis, 2013). However, in the second half of the 19th century, the spatial structure of Izmir has started to change allowing penetrations across ethnical groups. As an example, the wealthiest families moved to the Frank Quarter, regardless of their ethnic or religious backgrounds. The Franks, on the other hand, moved to the Greek and Armenian Quarters; the Jews to the Muslim Quarter; and the Armenians to the Jewish Quarter. In other words, the second half of the 19th century, the city population was spatially restructured in a more flexible and less clustered manner (Smyrnelis, 2013). The period starting from the late 18th century to the end of the first half of the 19th century is selected for the study, as the spatial organization of the city was then heavily based on cultural factors. The street data used in this study is obtained from the “City Plan of Smyrna” published in Leipzig, by Joseph Meyer (1796-1856), a German industrialist and publisher. In Fig 2, the streets in each of the five quarters are presented pertaining to the first half of the 19th century. The total number of edges (links or routes), nodes (intersections or link ends) and the total length of edges at the quarter level are presented in Table 1. The highest total length of edges is in the Greek Quarter, followed by the Turkish and Frank Quarters. Similarly, the Greek Quarters has the highest number of nodes, followed by the Turkish and Jewish Quarters (Table 1).

Table 1. Descriptive statistics for the nodes and edges at the quarter level.

Quarter (Neighborhood)	Total Area (ha)	Number of Nodes	Number of Edges	Total Length of Edges
Armenian	73.907	186	282	16,842
Frank	125.609	296	448	29,918
Greek	222.655	514	854	55,176
Jewish	61.989	323	424	16,931
Turkish	151.084	465	631	35,567

3. Analysis and results

Six different indices are used in this study to analyze and compare the urban street patterns in the quarters of Izmir in the 19th century. These indices are: (1) edge density, (2) edge sinuosity, (3) eta index, (4) node density, (5) order of a node, and (6) beta index. All of these six indices are first calculated at the at the quarter level, which is the global level. Further, three of these indices, including edge sinuosity, edge length, and order of a node are calculated at the edge or node level, which is the local level. Edge density is the ratio of the total length of edges to the total area. Edge sinuosity is a measure of straightness. It is the ratio of the shortest distance between the two ends of an edge to its length. Sinuosity is equal to 1 when the edge is a straight line. Node density is the ratio of the total number of nodes to the total area (Hammond and McCullagh, 1978). Order of a node denotes the number of edges intersecting at this particular node. Eta index is the average edge length, derived by dividing the total edge length to the number of edges. Finally, beta index, is the average number of edges per node, derived by dividing the total number of edges to the total number of nodes (Kansky and Danscoine, 1989). The average values for the six indices are presented in Table 2.

Table 2. Average values for the six indices at the quarter (global) level.

Quarter (Nighborhood)	Edge Density	Edge Sinuosity	Eta Index	Node Density	Order of Nodes	Beta Index
Armenian	227.884	0.988	59.724	2.517	3.156	1.516
Frank	238.186	0.986	66.782	2.357	3.118	1.514
Greek	247.809	0.986	64.609	2.308	3.232	1.661
Jewish	273.124	0.973	39.931	5.211	2.709	1.313
Turkish	235.416	0.966	56.367	3.078	2.641	1.357

Table 2 shows that edge density and node density is the highest in the Jewish quarter. The Jewish quarter has also the lowest eta index value, which indicates that the average route segment length (average edge length) is in this neighborhood. The lowest value for the beta index is also present in the Jewish quarter. That is to say, there are fewer edges per node than any of the quarters in the study, indicating a denser network in nodes. The Turkish quarters follows the Jewish quarter when the edge sinuosity, eta index, node density, order of nodes and beta index are considered. These findings show that the street network in the Jewish quarter is more developed compared to the other quarters in the city. A plausible explanation for this finding is that the Jewish quarter is partly the bazaar (central business area) and the market of the city in the 19th century. This part of the city is still the heart of the local commerce activity in the city of Izmir. Edge sinuosity and order of nodes are higher in Armenian, Frank and Greek quarters. This finding is closely related to the fact that these quarters have a grid or grid-like plan. The grid plan requires that the streets are connected at right angles forming four-way intersections, which increases the order of nodes and edge sinuosity index values. The values in Table 2 are the average values for the six indices included in the study. These indices are calculated at the quarter level, which is the global level. However, eta index (edge length in case of a single edge) and edge sinuosity and can be calculated at the edge level, and order of a node can be calculated at the node level for each quarter. These local indices can be subject to statistical tests, as they are observed samples. Table 3 shows the descriptive statistics for these three indices at the local level.

Table 3. Descriptive statistics for the three indices at the node or edge (local) level.

Index	Descriptive	Armenian	Frank	Greek	Jewish	Turkish
Eta Index (Edge Length)	n	282	448	854	424	631
	Minimum	4.9	4.6	4.5	3.3	0.1
	Maximum	637.9	412.9	316.1	242.1	242.2
	Mean	59.7	66.8	64.6	39.9	56.4
	Standard Deviation	46.3	53.8	45.0	30.5	40.1
Edge Sinuosity	n	282	448	854	424	631
	Minimum	4.9	4.6	4.5	3.3	0.1
	Maximum	637.9	412.9	316.1	242.1	242.2
	Mean	59.7	66.8	64.6	39.9	56.4
	Standard Deviation	46.3	53.8	45.0	30.5	40.1
Order of a Node	n	186	296	514	323	465
	Minimum	1.0	1.0	1.0	1.0	1.0

Maximum	4.0	5.0	4.0	4.0	4.0
Mean	3.2	3.1	3.2	2.7	2.6
Standard Deviation	0.6	0.6	0.5	0.9	0.9

The mean values for these three indices for the five different quarters (Armenian, Frank, Greek, Jewish, and Turkish) are compared using one-way analysis of variance (ANOVA). The results show that the three indices for the quarters do not belong to the same population. The null hypothesis that these five quarters have equal means is rejected for all the three indices. The results are statistically significant at the 0.001 level. The F-statistic for the eta index is 27.748, edge sinuosity 11.385, and order of a node index 54.8. Further post hoc tests are conducted to determine which quarters differ significantly in term of these three indices. The results of the least significant difference (LSD) indicate that the Armenian, Frank and Greek quarters do not differ significantly in eta index, edge sinuosity, and order of a node. However, the Turkish Quarter and the Jewish quarter differ from the remaining three quarters and from each other in the means for these three indices. These findings are statistically significant at the 0.05 level.

4. Conclusion

In this study, the graph theory is used to compare the spatial structure of street networks in the quarters (neighborhoods) of Izmir in the 19th century. Six different spatial indices are calculated: (1) edge density, (2) edge sinuosity, (3) eta index, (4) node density, (5) order of a node, and (6) beta index. All of these six indices are first calculated at the global level. Further, three of these indices including edge sinuosity, edge length, and order of a node are calculated at the edge or node level. The results showed that the urban street pattern varies with the cultural landscape. Moreover, the findings regarding that that the Armenian, Frank and Greek quarters do not differ significantly in the means for the three local indices, and the Turkish Quarter and the Jewish quarter differ from these three quarters and from each other, point out that religion may have determining role in forming the spatial structure. Further research may consider different spatial indices and may focus on a wider time spectrum to generalize these results.

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